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INVESTIGATION OF GREEN LIQUOR CLARIFIER DESIGN FEATURES

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ABSTRACT

As pulp mills attempt to incrementally increase production, the green liquor clarifier is forced to handle more liquor, often exceeding its design optimum. The goal of this research is to determine the effect of higher liquor feed rates on clarifier performance and the effect of certain design features in aiding performance.

Dye tracer studies recorded on videotape show a radical change in the fluid flow patterns as the feed rate is increased beyond the optimum design rate for a model clarifier. These changes involve increased turbulence and a large backmixing pattern in the clarifier. Experiments using a slurry of calcium carbonate showed a corresponding decrease in the solids removal efficiency for the clarifier. This decreasing trend was not changed with different feedwell designs or with polymer addition, although there was an increase in solids removal at each feed rate with polymer addition. The placement of a bed of metal dendrite fibers between the feedwell and the clarifier wall also increased the solids removal efficiency and did not significantly decrease as the clarifier feed rate was changed. The increased solids removal at the optimum feed rate was the same as with polymer. These results show promise for using dendrite fibers as a possible method to incrementally increase clarifier capacity.

INTRODUCTION

In the Kraft chemical recovery process, spent liquor from a cook is burned in the recovery furnace. The resulting chemicals are a mixture of sodium sulfide and sodium carbonate known as smelt. The smelt is dissolved in water in a dissolving tank to form green liquor. However, not all of the solids get dissolved; there is an insoluble portion of the smelt known as *dregs*. Dregs need to be removed from the green liquor, or else they will contaminate the lime cycle. Most mills in the United States use a clarifier to remove dregs by sedimentation. For most mills, an acceptable clarity for green liquor is 100 parts per million (ppm) or less [1]. If the solids content of the green liquor is more than 100 ppm, then mill operators run the risk of working with contaminated lime and reduced causticizing efficiency.

Since the pulp mill is a very capital-intensive facility, many pulp mills that want to increase production prefer to do so without making major changes in equipment. A consequence of increased production is that the chemical recovery process must handle more liquor. That means more green liquor will be flowing through the clarifier, sometimes in greater amounts than the clarifier was designed to handle. The increased flow may lead to backmixing in the clarifier, which reduces settling. The backmixing will interfere with the flocculation and settling of the dregs. More dregs will end up in the overflow, and therefore create the contamination problem that operators were trying to avoid.

This research attempts to quantify the effect of higher-than-design feed rates on the solids removal efficiency of a model clarifier; provide a qualitative look at the flow patterns in the clarifier at optimum feed rates and higher; and study the effect of typical and novel design features on the solids removal efficiency of solids in a clarifier. This involves the design and construction of a model clarifier made from clear acrylic to facilitate the viewing of flow patterns.

Current clarifier technology for green liquor is reviewed in Green and Hough [1], as well as Cornell [2]. These works focus primarily on how to operate the clarifier and do not contain much research data. The origin of dregs and their effects has been well documented by Magnusson et al. [3]and Liden [4]. Most of the work involving hydraulics in clarifiers has been completed by researchers in the field of wastewater treatment [5-12]. These works cover areas such as particle flocculation [6-8], wave actions[9-10], density currents [11], and inlet design [12].

CLARIFIER DESIGN

A model clarifier was designed from the results of settling tests using a standard method [13] with dregs samples from The Mead Corporation Coated Board Division. The design calculations were completed using the Talmadge-Fitch method for designing clarifiers [5]. The clarifier was built from clear acrylic to allow for visual observations. Four different feedwell (inlet port) designs were employed. Three of the designs were analogous to current feedwell designs used in green liquor clarifiers. One design has a baffle on the side of the cylindrical feedwell. Another design uses a metal screen which is set diagonally inside the feedwell. The third design is an open feedwell with parallel rings inside and a small section cut from the side. The fourth feedwell is a blank cylinder that is closed at the top, and is used as a control. The feedwells were sized according to the Froude model law, which states that the most important parameter to keep constant for building scale clarifier models is the Froude number [14]. The Froude number is a ratio of inertial forces (i.e., fluid velocity) to gravitational forces; it can be calculated densitmetrically by the following equation [12].

$$F_D = \frac{U}{[(\Delta\rho/\rho)gH]^{1/2}} \qquad \textbf{(1)}$$

where U = velocity entering the feedwell (m/s)
$\Delta\rho$ = density difference between the feed and the pure liquid (kg/m^3)
ρ = density of the pure liquid (kg/m^3)
g = gravitational constant (m/s^2)
H = height of the tank (m)

Froude numbers for wastewater clarifiers are usually in the order of 10^{-5} [14].

DYE TRACER RESULTS

Fluorescein dye was allowed to flow into the clarifier, which was filled with clear water, at different feed rates and with different feedwell designs. At the optimum feed rate (343 ml/minute or 0.560 ml/cm^{2}min), the dye entered the clarifier through the feedwell outlet and formed an annular pattern around the shaft. Some small eddies were visible in the flow. Essentially, the fluid appeared to be falling into the clarifier, which would seem to be the ideal situation for settling solids. Figure 1 is a schematic representation of the flow pattern at the optimum flow rate.

As the feed rate increased from 343 to about 429 ml/minute (0.700 ml/cm^{2}min), the annular pattern disappeared. Very little dye was visible on the right side (entry side) of the shaft, whereas on the left side dye was dispersing from the shaft at an angle of about 5-7 degrees. The eddies were larger than the previous run and easier to see. In the baffle and screen designs, a small plume of dye would appear to the right of the shaft, but would disappear within the first 10 seconds of the test.

At 515 ml/minute (0.841 ml/cm^{2}min), the eddy size and speed continued to increase. The departure angle from the shaft was about 10 degrees at these feed rates. There was no dye at all to the right of the shaft for the closed feedwells. Figure 2 shows a schematic digram for this type of flow pattern.

The open feedwell was expected to behave differently from the closed feedwells, since it had no cap on top and a section cut out of the side; there was nothing to force the flow in a downward direction. At the lowest level the flow came out in a U-shaped pattern. Slow moving eddies were visible at the optimum feed rate. These eddies were larger than the eddies from the closed feedwells. A small plume of dye was visible coming out of the top and the bottom of the open feedwell and held for all flow levels.

As the feed rate increased for the open feedwell, the U-shaped pattern disappeared and gave way to a conical pattern that resembled a spray. This "spray" got larger in size as the feed rate increased. Also at feed rates of 429 ml/minute and higher, the fluid would reach all the way to the far wall, causing the fluid to recirculate off the wall and back into the main flow pattern. The vast majority of the dye diffuses upward with the open feedwell. However, the entire clarifier does eventually fill up with dye. Figure 3 shows these particular patterns for open feedwells. The difference in flow patterns for the open and closed feedwells indicates that there should be a corresponding difference in the solids removal efficiency for respective feedwells. These dye tracer results also indicate that there should be a significant difference in solids removal efficiency for the different feed rates.

Viewing at 10 times normal speed allowed for the viewing of slow moving bulk patterns along the bottom of the clarifier. The results tend to indicate the existence of large, relatively slower moving backmixing patterns, especially for the closed feedwells. At the high feed rates, a relatively large circular flow pattern could be seen in the lower left hand side of the clarifier after enough dye had come into the system. Figure 4 shows this pattern schematically. The time at which that particular pattern began to appear was dependent on the flow rate entering. At the optimum flow rate (343 ml/min), the circular pattern never appeared.

The fluorescein dye readily diffused into the rest of the clarifier, making visual observations impossible after about 1 minute of viewing on videotape. It also made quantitative data impossible to gather. Visual observation of the solids settling experiments showed no qualitative differences in the flow patterns in comparison with the dye.

It is definite that there is a significant change in fluid behavior as the feed rate is increased. Turbulence as indicated by the presence of eddies increases with increasing feed rate. Closed feedwells do serve to force the flow down into the clarifier, while the open feedwell allows the fluid to flow upward. It was expected that the solids removal efficiency would get worse as the feed rate increased. The dye tracer results also lead to the expectation that feedwell design will have an effect on the solids removal efficiency of calcium carbonate solids in the clarifier.

SOLIDS REMOVAL EFFICIENCY

After the dye tracer tests, a 1000 ppm slurry of calcium carbonate and water was made and used for solids settling experiments. Calcium carbonate from ECC International was used to eliminate the need to heat the green liquor to mill conditions, as well as avoid environmental and safety issues in dealing with green liquor. Overflow and inlet total suspended solids (TSS) were tested using a standard method [15], and used to calculate solids removal efficiency, which is defined as the amount of solids removed (inlet TSS - overflow TSS) divided by the inlet TSS. Solids removal efficiency is expressed as a percentage.

Flow Rate, Feedwell Design, and Polymer Usage

There was a general decrease in solids removal efficiency as feed rate increased from optimum up to 515 ml/minute for the blank and open feedwells. The baffle and screen feedwells showed an increase in solids removal efficiency from 343 to 429 ml/min, but then decreased rapidly as the feed rate went up to 515 ml/min. The blank feedwell showed an increase in solids removal efficiency as the feed rate increased from 429 to 515 ml/minute (see Figure 5), but analysis of the data showed this to be a statistical anomaly. The data points in Figure 5 are the average of two separate runs in a randomized completed block experimental design with replication. One of the runs for the blank feedwell at 515 ml/min had the highest solids removal efficiency for any of the runs in that block. This is in contrast to the other seven runs at 515 ml/min (for all feedwell designs) which showed the lowest settling efficiencies in the block. While this piece of data threw off the trend for the blank feedwell and increased the experimental error, the conclusions have not changed. For all feedwells, the average decrease in solids removal efficiency going from 429 to 515 ml/min was 21.3 %. It would seem that the nonideal feed patterns that form as flow rate increases do indeed have a detrimental effect on clarifier performance.

Using the same data for studying the effect of feed rate, it was found that feedwell design had a significant effect on the solids removal efficiency at the optimum feed rate. However, as the feed rate increased the significance of feedwell design changed. Figure 5 shows evidence for this. In going from 343 to 429 ml/min, the baffle and screen designs gave a slight increase in solids removal efficiency, while the blank gave the expected decreases and the open was virtually unchanged. In going from 429 to 515 ml/min, the baffle and screen designs have very large drops in efficiency where they fall below that of the open feedwell. This would suggest that the baffle and screen designs are able to handle some feed rates higher than optimum, most likely due to the baffle or screen working to promote turbulence and flocculation inside the feedwell. There is an obvious limit to this effect. These two and the open feedwells average between 40 and 45 percent solids removal efficiency at high feed rates. Krebs states that while some turbulence is needed for flocculation, there is an upper limit that exists. This is usually expressed in terms of a mean velocity gradient (G-value) [12]. It is probable that as the feed rate increased in these experiments, the upper turbulence limit was passed. That factor, combined with the bulk flow patterns shown previously, led to a reduction in the solids removal efficiency at high feed rates.

The polymer used was an anionic polyacrylamide from Betz. Polymer addition was found to have a positive effect on solids removal efficiency for all feedwell designs and feed rates. This should come as no surprise, since polymer treatments for green liquor clarifiers have been practical since the 1970s [16]. What was found was that the effect of polymer addition was subordinate to feed rate for the closed feedwells. An example of this is shown in Figure 6.

The open feedwell was more suited to polymer application than the three closed feedwells. It is believed that the two parallel rings keep the majority of the flow in a relatively small area of the feedwell, which allows the polymer to come in contact with more solids. The result is that the effectiveness of the polymer (i.e., the difference in solids removal efficiency with and without polymer) stays between 30 and 40 percentage points for the open feedwell even at higher flow rates, where the other feedwells fall below 20 percentage points at the higher flow rates.

Dendrite Fibers

A five centimeter thick bed of metallic dendrite fibers was placed in the clarifier at the same depth as the feedwell (about 20 cm above the bottom). The dendrite fibers, supplied by Battelle Laboratories, are small metal fibers about 13 mm long. They have a very large surface area to volume ratio. The void volume of a nested bed of these dendrites is about 95 %, which is about the same as activated charcoal. In studying the effects of a bed of dendrite fibers and feed rate, it was found that the use of these fibers not only increased solids removal efficiency, but also caused the effect of feed rate to become insignificant. The reason for this change involves the placement of the bed of fibers relative to the bulk flow patterns. Recall Figure 4 which showed a potential backmixing pattern in the bottom of the clarifier. The placement of a 5-cm bed of dendrite fibers, with the bottom of the bed even with the bottom of the feedwell, essentially cuts off the top of that backmix pattern. The backmixing brings solids into the fiber bed where they are held up by impingement. Liquid flows readily through the void spaces, Figure 7 shows a typical result for solids removal efficiency for closed feedwells with the dendrite fiber bed.

The increase in solids removal efficiency by using the dendrite fiber bed was true for all feed rates and was also independent of feedwell design. This was true despite the fact that the open feedwell did not force fluid below the bed. The fiber bed position was such that about one third of the fluid flow pattern was in contact with the fiber bed. As the feed rate increased, the spray pattern became wider and more solids were caught in the bed than perhaps what would be the case at the optimum feed rate. Figures 8 and 9 show schematically the fluid flow patterns in the presence of a dendrite fiber bed for closed and open feedwells.

These results indicate that there is good potential for the use of a bed of dendrite fibers as way to increase the capacity of the green liquor clarifier without sacrificing liquor quality.

The data show that there is no clear leader between dendrite fibers and polymers in terms of solids removal efficiency. However, there are several potential advantages for dendrite fibers. This first is the insensitivity to feed rate. The increase in feed rate directly translates into capacity increases. The second advantage is cost. Adding a bed of dendrite fibers would be a one time capital cost, rather than the constant cost that comes with polymer. There are several unknowns that need to be investigated, including the interaction mechanism between the solids and the dendrite fibers, the amount of time required before regeneration of the fibers is required, the method of fiber regeneration, and the effect of different bed packings.

CONCLUSION

There is a definite change in the bulk fluid patterns leaving the feedwell as feed rate increases. The size of eddies in the flow pattern increase with feed rate. An increase in feed rate also causes a large relatively slow moving backmix pattern in the lower portions of the clarifier. These patterns do not change when solids are introduced to the fluid flow. Increasing the flow rate into the clarifier above its optimum decreases the solids removal efficiency of the clarifier. This is true with or without polymer and for all feedwell designs. Different feedwell designs do change the solids removal efficiency, but this change gets smaller as the feed rate increases. The addition of polymer increases the solids removal efficiency by about 10 to 30 %. Feedwell design does have an effect on the performance of polymer in the settling slurry. The addition of a bed of dendrite fibers causes a 20-35 percentage point increase in solids removal efficiency. Solids removal efficiency in the presence of dendrite fibers was insensitive to increasing the flow rate or changing the feedwell design. There was no significant difference when the results of polymer and metallic dendrite fibers were compared, but dendrites show great potential in terms of cost-effectiveness.

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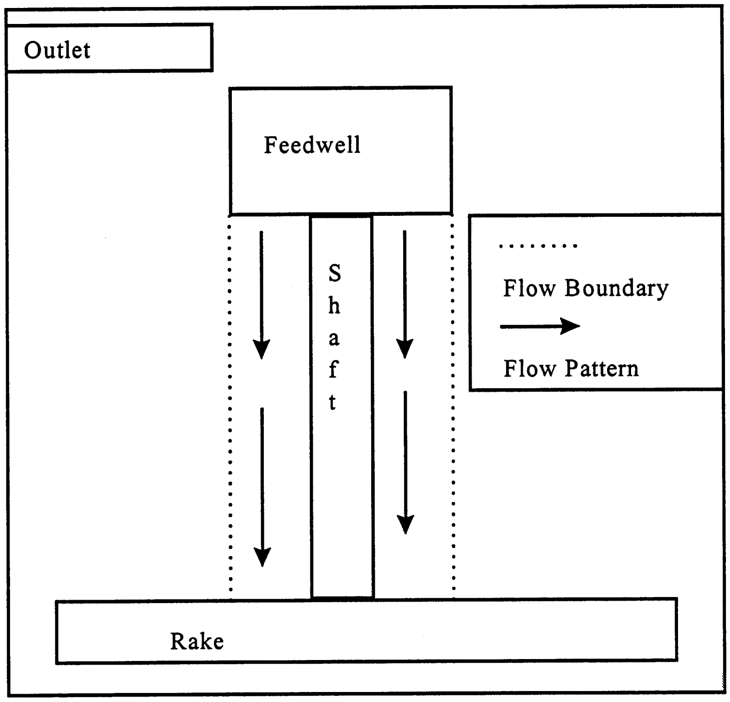


Figure 1. Flow pattern for closed feedwells at optimum feed rate (not to scale).

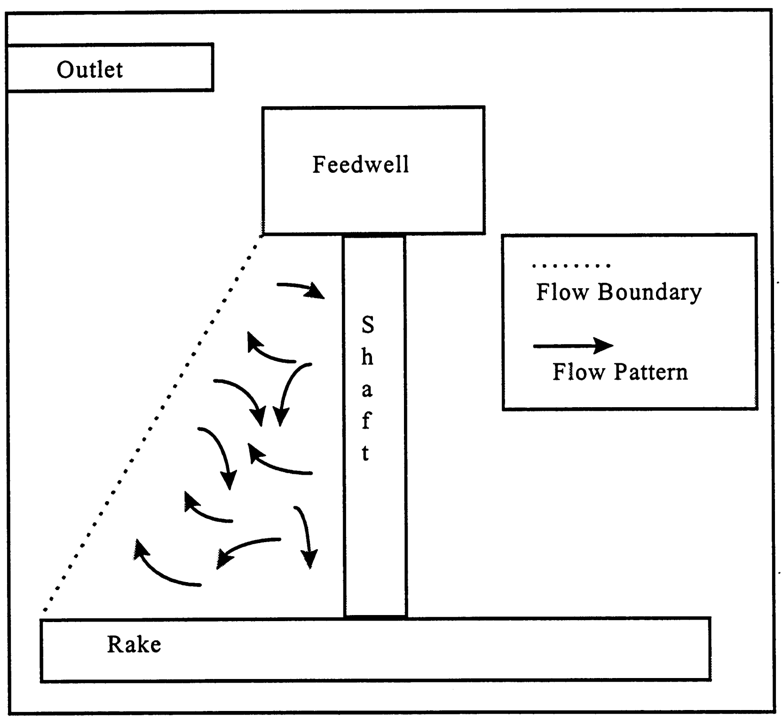
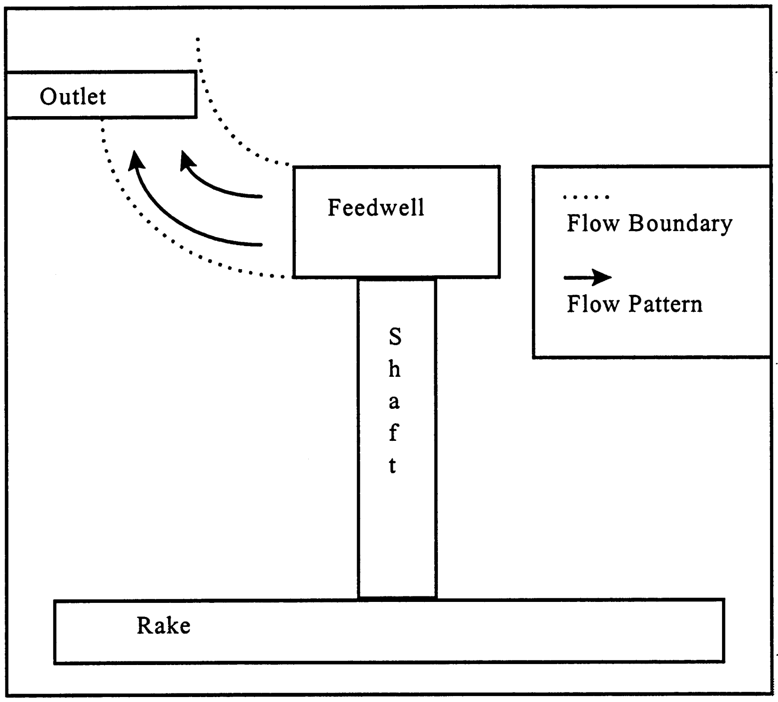
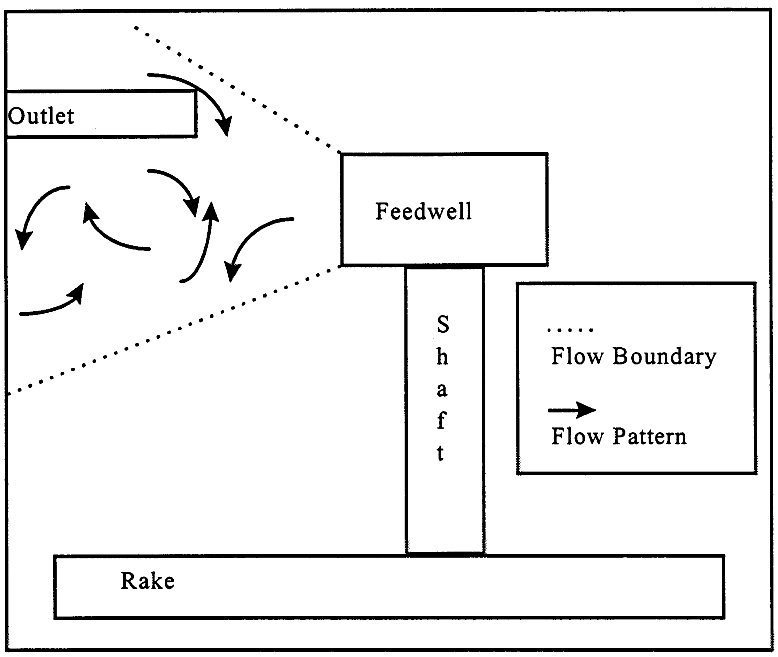


Figure 2. Flow pattern for closed feedwells at feed rates > 429 ml/min. (not to scale).



(a) Optimum feed rate



(b) High feed rate

Figure 3. Flow patterns for open feedwells at different flow rates (not to scale).

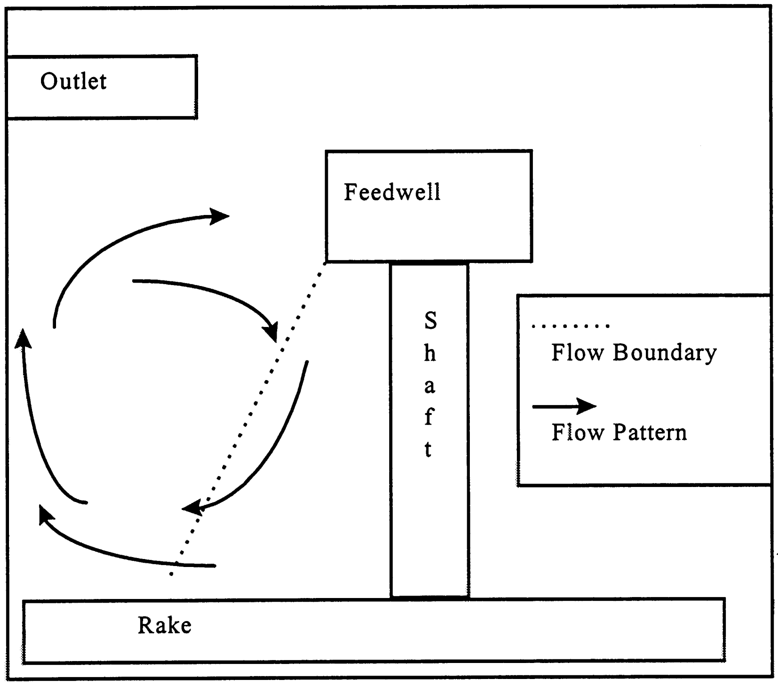


Figure 4. Schematic of a backmixing pattern at high feed rates (not to scale).

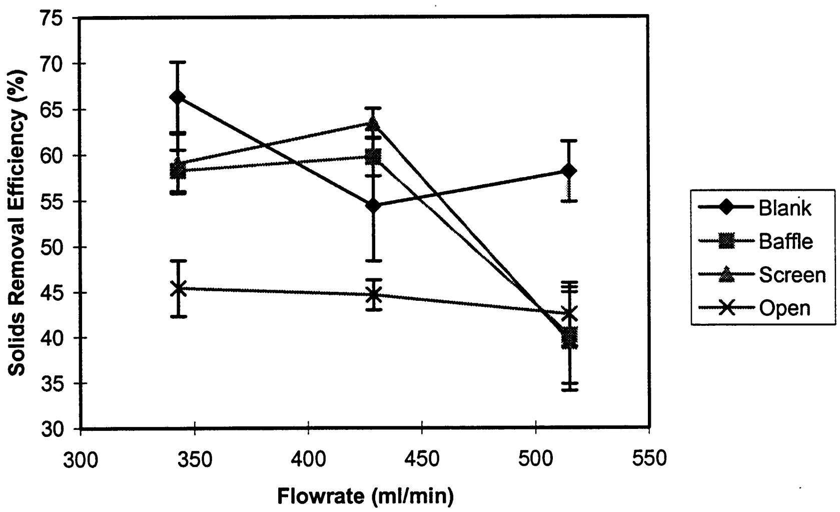
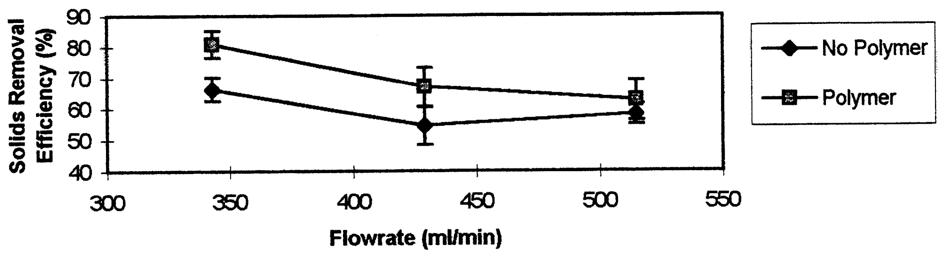
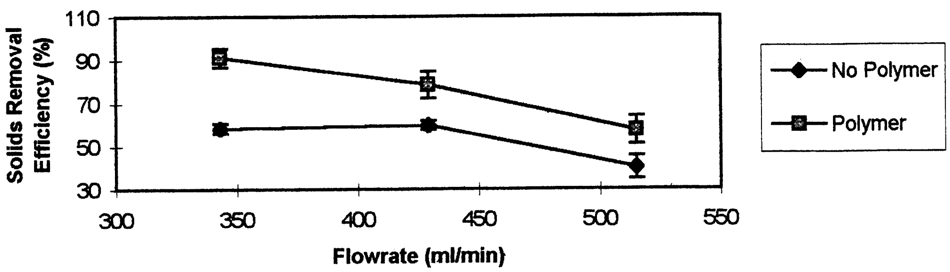


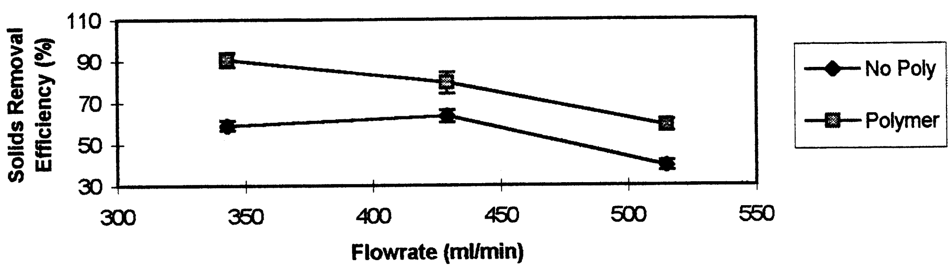
Figure 5. Effect of feed rate on solids removal efficiency for various feedwell designs.



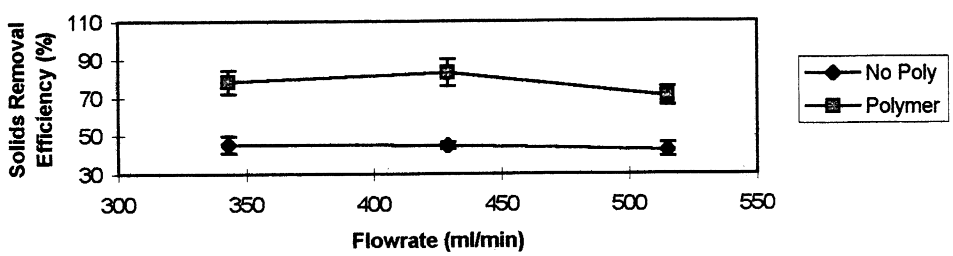
(a) Blank feedwell



(b) Baffle feedwell



(c) Screen feedwell



(d) Open feedwell

Figure 6. Effect of polymer treatment on solids removal efficiency for various feedwells.

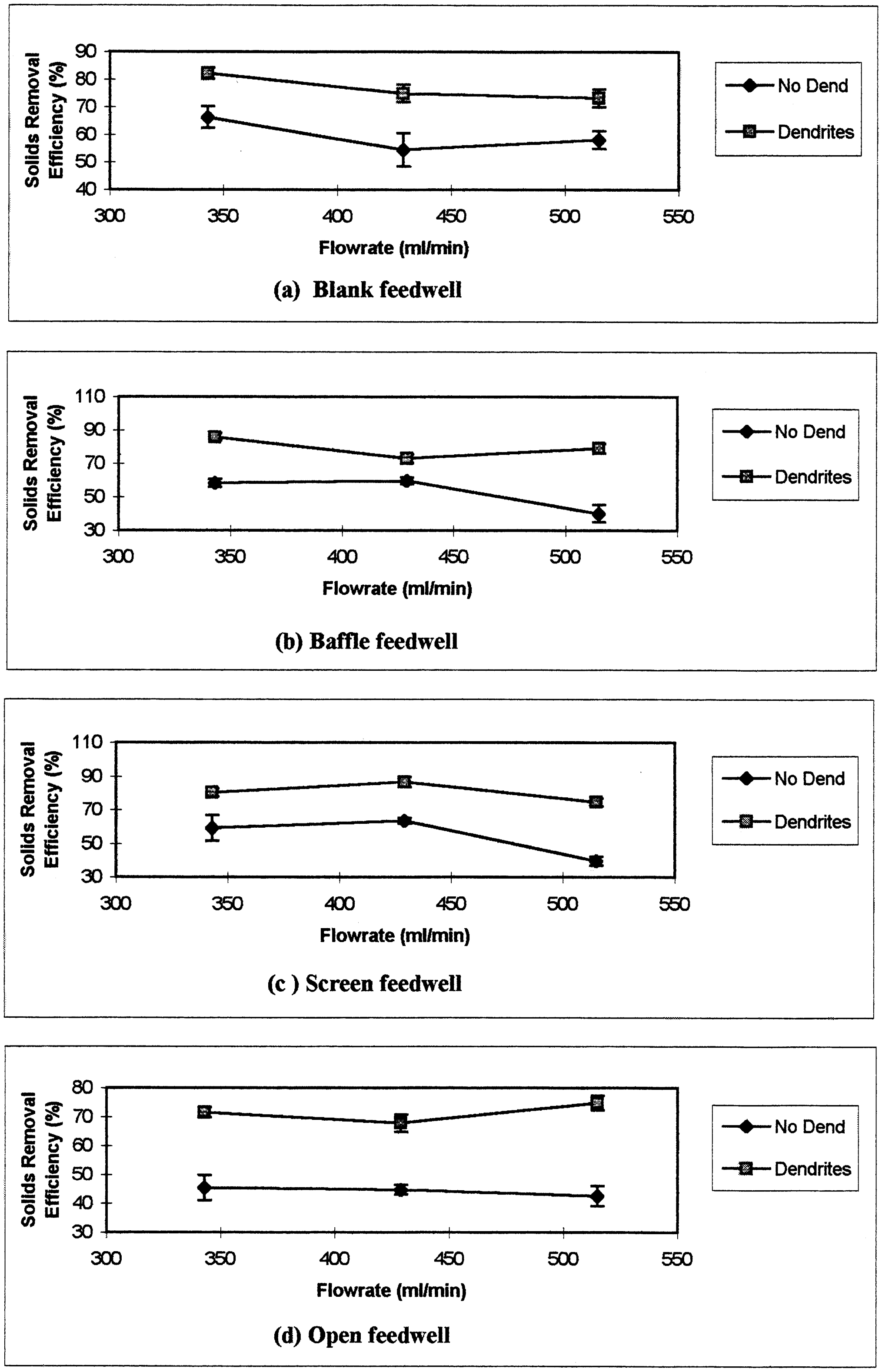


Figure 7. Effect of dendrite fibers on the solids removal efficiency for various feedwells.

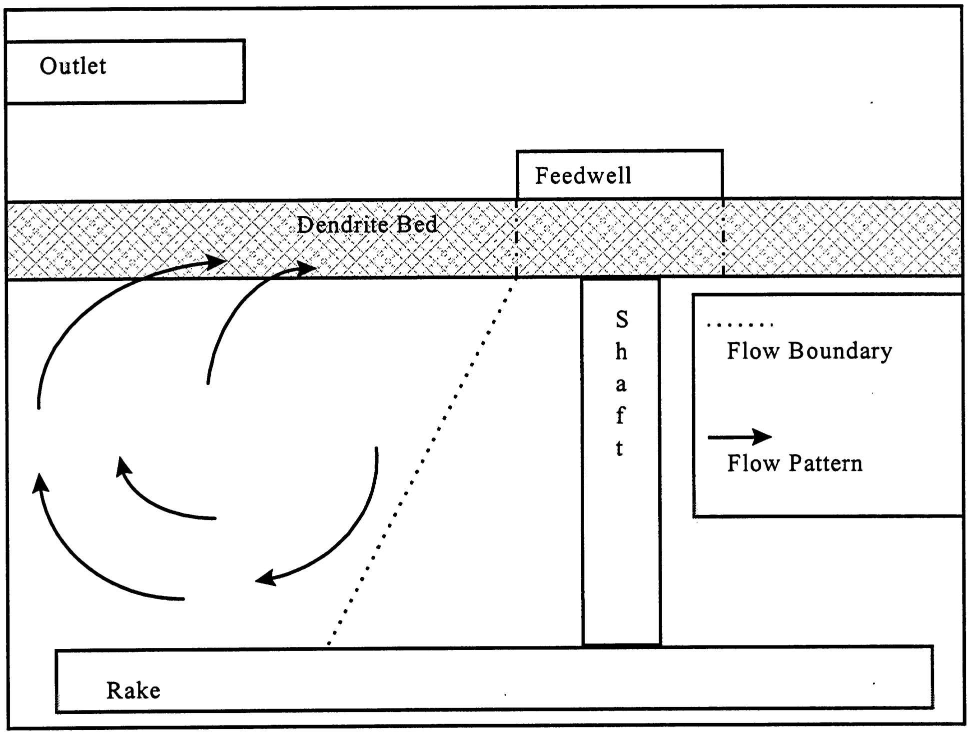


Figure 8. Backmixing pattern with a dendrite fiber bed (not to scale).

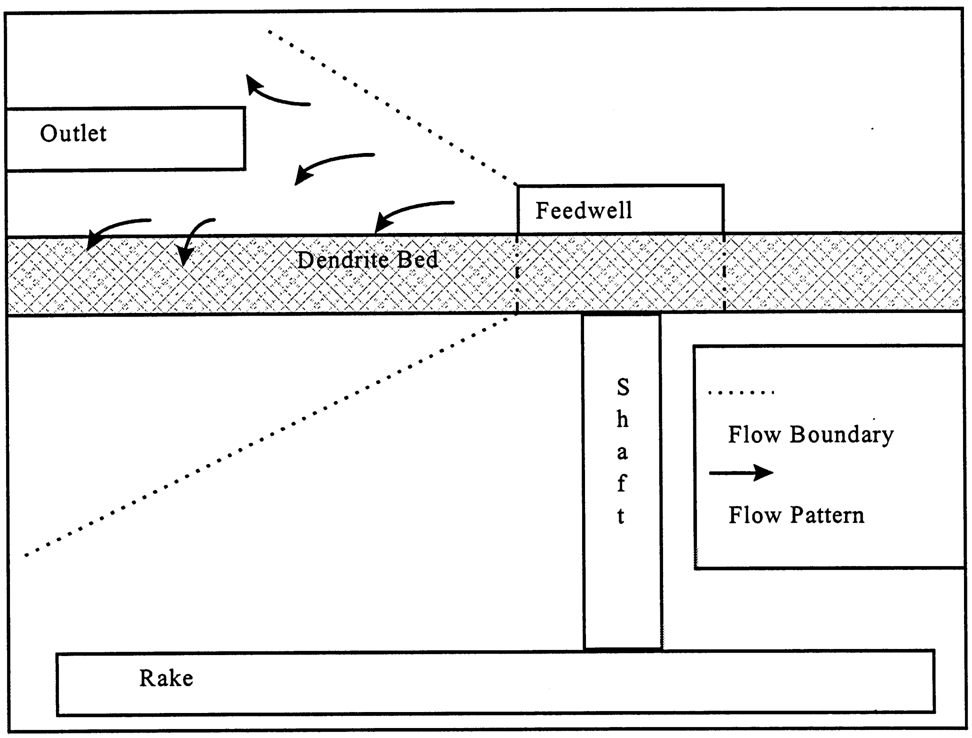


Figure 9. Fluid flow from an open feedwell with dendrite fibers.